# NAVAL HEALTH RESEARCH CENTER

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*P. G. Law*
*H. W. Goforth, Jr.*
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*J. L. Reid*

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NAVAL HEALTH RESEARCH CENTER
P. O. BOX 85122
SAN DIEGO, CALIFORNIA 92186 – 5122



NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
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P. G. Law[1]
H. W. Goforth, Jr.
S. E. Kaupp[1]
W. K. Prusaczyk
K. E. Schneider[1]
J. L. Reid[1]

Naval Health Research Center
P.O. Box 85122
San Diego, CA 92186-5122

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[1] GEO-CENTERS, INC., Fort Washington, MD 20744

## SUMMARY

Problem.

Physically preparing the body for future events is a primary concern for military personnel. Unexpected injuries and performance decrements can potentially hinder optimal performance during an operation or mission. Unaccustomed eccentric muscle exercise (e.g., the landing phase of running, hiking downhill, walking down stairs) can result in severe muscle soreness, strength loss, and reduced joint range of motion around a joint. However, these symptoms are significantly reduced when the same eccentric-biased activity is repeated 1 to 6 weeks later.

Objective.

It is often not feasible for personnel to perform the same exercise that will be encountered during an operation or mission (e.g., marching 10-15 miles over hilly terrain while carrying a 50 kg pack). Personnel may be able to prepare or toughen the muscles in advance by performing a similar, but a less time consuming eccentric activity. Therefore, the primary objective of this study was to determine if two 3-mile downhill training runs, performed one week apart, could reduce the adverse symptoms that may be associated with a subsequent novel mountain hiking exercise (i.e., muscle damage and strength loss). A secondary purpose was to document how leg muscles respond to a novel mountainous hiking exercise (with a standardized pack weight).

Approach.

Special operation Marine Corps volunteers were assigned to either a treatment (downhill running) group (n=12) or a control group (n=8). The downhill running group performed two 3-mile downhill runs (1 week apart), while the control group followed their normal training schedule. Two weeks after the second downhill run, both groups completed two 6-mile mountain hikes (2 days apart) while carrying 30% of their body weight. Muscle soreness, isometric leg endurance, an indicator of muscle damage [plasma creatine kinase (CK)], and a rating of perceived exertion (RPE) were measured before and after the downhill runs and the hikes.

Results.

*Downhill Runs*: Muscle soreness was significantly less after the second downhill run compared to the first downhill run. One day after the first downhill run, plasma CK concentration was significantly elevated above prerun levels and remained elevated in the remaining sampling periods.

*Hikes*: Subjects in the downhill running group did not exhibit significantly greater reductions in muscle soreness, CK, or in strength loss after either hike, compared to the control group. Hiking performance (i.e., hiking times) was also not significantly improved by prior downhill running. Dry bulb temperature and the incidence of blisters were greater during the second hike.

When data from the downhill running group and the control group were combined, 1) subjects hiked slower, and heart rate and RPE were higher in the second hike compared to the first hike, 2) isometric leg endurance immediately after exercise was significantly less compared to prehike leg endurance, for both hikes, 3) plasma CK concentrations were significantly elevated above prehike concentrations, 24 h after the first hike, and 4) muscle soreness was significantly increased above prehike 1 scores, 24 h after each hike and prior to the second hike (48 h after the first hike).

## Conclusions.

Downhill running does not appear to provide significant protection against muscle soreness, muscle damage (CK), or short-term isometric strength losses that accompany unaccustomed mountain hiking (with pack weight). Changing the mode of exercise and adding an external load may have influenced the degree and specificity of eccentric muscle damage and adaptation.

# INTRODUCTION

Specific or deliberate training of muscle groups within a physical training program is a key element for optimizing performance. This principle is also known as training specificity. Muscle adaptation is influenced by the mode or type of muscle contraction, and by the intensity, duration, and frequency of the contractions. For example, a muscle that is lengthened during a contraction (eccentric contraction) produces a higher force at a lower oxygen cost, compared to a muscle that shortens during a contraction (concentric contraction) (Gray & Chandler, 1989; Knuttgen, 1986). Researchers have demonstrated greater strength gains following a training program of maximal eccentric contractions compared to a similar training program of concentric contractions (Colliander & Tesch, 1990; Komi & Buskirk, 1972; Mannheimer, 1969). These investigations also demonstrated that strength gains associated with eccentric contractions are often accompanied by joint and muscle pain and injury.

Unlike concentric exercise, eccentric exercise, when performed for the first time, is often followed by muscle soreness, muscle damage, short-term strength loss, impaired muscle glycogen repletion, muscle swelling, and reduced range of motion around a joint (Abraham, 1977; Ebbeling & Clarkson, 1989; Howell, Chila, Ford, David, & Gates, 1985; Sargent & Dolan, 1987). Exercising with these symptoms can lead to a change in posture, compromise shock absorption, and lead to acute muscle and connective tissue injuries (Smith, 1992; Hamill, Freedson, Clarkson, & Braun, 1991). For example, Hamill, et al. (1991) demonstrated a reduction in maximal knee and hip flexion after a novel downhill run which resulted in altered mechanics during the support phase of a second run performed 3 days later.

These manifestations associated with unaccustomed eccentric exercise usually appear 1 to 2 days after the exercise bout (Ebbeling & Clarkson, 1989), but commonly disappear within 2 days to 2 weeks after the exercise (Smith, 1992; Ebbeling & Clarkson, 1989). Muscles can adapt to this exercise stress and symptoms are often reduced or disappear when the exercise is repeated 1 to 6 weeks later (Clarkson & Tremblay, 1988; Newham, et al 1987). Muscles are often able to resist even greater forces after eccentric training (Colliander & Tesch, 1990; Komi & Buskirk, 1972; Mannheimer, 1969). This phenomenon follows the training specificity principle; it is eccentric, not concentric training that prevents muscle soreness and muscle injury in subsequent eccentric activities (Armstrong, Ogilvie, & Schwane, 1983; Schwane, Williams, & Sloan, 1987).

Researchers and applied physiologists agree that eccentric actions are essential for peak performance and should be included in every training program (Albert, 1991; Colliander & Tesch, 1990). Albert (1991) suggests eccentric training can enhance a physical training program by not only increasing strength performance, but also by reducing muscle and connective tissue strains and tears through strengthening of the tissues. Examples of eccentric leg training exercises include walking down stairs, running or hiking downhill, lowering weights during knee flexion, and squatting exercises (e.g., "boot slappers").

Military personnel may benefit from performing specific eccentric exercises before operations or missions involving eccentric-biased contractions. Preparing for future events is a primary concern for special operations combat units such as U.S. Navy Sea-Air Land/SEALs, Army Rangers, Marine Corps Force Reconnaissance, and the Air Naval Gun Liaison Company. These individuals must be prepared to complete a variety of physically challenging activities involving significant amounts of eccentric contractions (e.g., running, mountain hiking, and parachute jumping). For example, operations or missions which are completed in hilly terrain often involve novel eccentric muscle contractions. In this scenario, repeated, high force, eccentric contractions of the leg muscles can be encountered during the downhill portion and are amplified by heavy pack loads (25-50 kg).

Since it is often not feasible to complete the same eccentric activity before the event, a training program incorporating similar eccentric-biased activity can be beneficial. It appears that the benefits of eccentric training may be observed after a relatively brief training period (Law, Goforth, Prusaczyk, Smith, & Vailas, 1994). This laboratory investigation, conducted on physically fit Navy and Marine Corps personnel, demonstrated that two 30-min downhill runs, completed 1 week apart, reduced muscle soreness and muscle damage (i.e., plasma creatine kinase concentrations), and maintained isokinetic muscle strength in subsequent downhill runs (Law et al,. 1994). Similar investigations confirm these findings (Byrnes, et al., 1985; O'Reilly, et al. 1987).

However, it has not been demonstrated that a downhill running program can effectively prepare muscles for a similar, but functionally different, eccentric leg exercise (i.e., mountain hiking with pack weight). Therefore, the primary purpose of this study was to determine if two downhill training runs could reduce muscle soreness, muscle injury, and strength losses which may accompany unaccustomed mountain hiking. Since there is limited information on the physiological effects of military hiking exercises, a secondary purpose was to document changes in muscle soreness and performance following novel mountain hiking.

## METHODS

### Subjects.

Special operations Marine Corps personnel from Camp Pendleton, CA were informed of the procedures and risks involved in this study prior to providing written consent. Subjects were recruited from 1st Air Naval Gun Liaison Company, and 9th Communications Battalion. Medical records and health questionnaires were reviewed by a physician to ensure participants were free from cardiovascular and orthopaedic disorders. Three-mile run times from each subject's current physical fitness test (PFT) (Table 2) and a survey of their current physical activity (mode, intensity, duration, and frequency of exercise in the past month) were obtained. Participants were

asked to maintain their current level of physical activity and refrain from additional eccentric leg activities during the study.

Twenty-four subjects volunteered for the study. Subjects were ranked according to their 3-mile run time, pair-matched, and assigned to either a treatment (downhill running) group or a control group. On the first day of testing, four individuals in the control group voluntarily terminated their participation in the study. Subjects in the downhill running group (n=12) completed two 3-mile downhill runs, one week apart, while subjects in the control group (n=8) followed their normal training schedule. Two weeks after the second downhill run, both groups completed two 6-mile mountain hikes.

Downhill Training and Hike Protocols.

Downhill runs and hikes were completed in the morning (start times between 0730-0830) on a 3-mile paved road (average grade = -3.5°; range = 0 to -13°). During the 3-mile treatment runs, participants in the downhill running group wore running shoes, T-shirt, and shorts. Subjects were transported by military vehicles to the top of the hill to begin the downhill runs. Downhill runs were completed at a moderate intensity based on 60-70% of the subject's age-predicted heart rate (HR) maximum (i.e., 220 minus age in years). Participants wore HR watches to assist in running at their predetermined HR target range. Subjects were instructed to keep within their HR range and ran with pacers (researchers) who monitored their HR. The two downhill runs were completed on the same course, one week apart.

Two weeks after the second downhill run, the downhill running group and the control group completed two 6-mile mountain hikes (48 hr apart) following the Marine Corps McCress Standards (i.e., 10-min rest every 50-min of exercise). Subjects hiked up the 3-mile paved road and were required to consume 1 liter of water at the top of the mountain (half way through the hike) during a mandatory 10-min rest period. Water was available during the hike, and physical well-being was monitored by researchers and medical personnel who followed the participants in a vehicle. Hikes were completed in standard battle dress uniform which included a soft cover hat, boots, and H-harness. All participants carried two canteens of water (1 liter each) and a rucksack or ALICE pack, equal to 30% of their body weight. Subjects were weighed in full gear before each hike and lead pellets were added to adjust the pack weight, if necessary. Hike start times were at random 1-3 min intervals, and subjects were instructed to perform their best effort without running. Time to complete the uphill and downhill portions of the hikes was recorded for each individual. Dry bulb temperature was recorded at the beginning and end of the hikes.

Measures.

Physiological and performance measures for the downhill runs and hikes are presented in Table 1.

Table 1. Measures for Downhill Runs and Hikes

| | **Run 1** | | | **Run 2** | | | **Hike 1** | | **Hike 2** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Measure** | Day 1 | Day 2 | Day 3 | Day 8 | Day 9 | Day 10 | Day 22 | Day 23 | Day 24 | Day 25 | Day 26 |
| Anthro-pometry | Run Group | | | | | | Control Group | | | | |
| Blood Sample | X | X | | X | X | | X | X | X | X | |
| Muscle Soreness | X | X | X | X | X | X | X | X | X | X | X |
| Leg Endurance | | | | | | | X--X | X | X--X | X | |
| Heart Rate | X | | | X | | | X | | X | | |
| RPE | | | | | | | X | | X | | |

RPE=rating of perceived exertion; X--X=measure collected before, and within 5-min posthike.

*Anthropometry.*

Age, height, and weight were obtained, and percent body fat was estimated from seven-site skinfold thicknesses (Jackson & Pollock, 1978; Siri, 1961).

*Muscle Soreness.*

Muscle soreness was rated by subjects following the application of a constant force (approximately 80 N) to nine muscle sites. The round plastic disk of a 60-cc syringe (4 cm diameter) was placed on the muscle site while the opposite end of the syringe was sealed and the plunger was compressed 20-cc units to create force. Soreness was recorded before and after (24 and 48 h) the downhill runs and hikes. Subjects rated muscle soreness using a 5-point scale (0=complete absence of soreness, 1=light pain, 2= moderate pain, 3=severe pain, 4=the worst soreness ever experienced). Numeric values in half-point increments were permitted. The nine sites measured for soreness on the front and the back of each leg were: gluteal, hamstring, upper and lower gastrocnemius, mid-vastus lateralis, medial and lateral heads of the vastus lateralis, and upper and lower tibialis anterior muscle groups.

*Rating of Perceived Exertion.*

A 6 to 20 incremental scale, with anchors from "very, very light" to "very, very hard" (Borg, 1970), was used to record subjects' rating of perceived exertion (RPE). Following standardized instructions, subjects gave an overall rating of the perception of effort half way through the hike (top of the hill) and at the finish (bottom of the hill).

*Heart Rate Monitoring.*

Heart rate (HR) response was measured during the downhill runs and the hikes using a watch-style receiver and a transmitter (Polar Vantage® XL). The transmitter was worn on the chest and the receiver was worn on the wrist (downhill runs) or taped to the pack (hikes). Average HR response during the hikes was determined from data recorded at 5-min intervals.

*Biochemical Indicator of Muscle Injury.*

Blood samples were obtained before (0600-0630) and 24 h after the downhill runs and hikes for the indirect measurement of muscle injury (i.e., plasma creatine kinase). Venous blood was collected from the antecubital vein in 10 ml EDTA-treated tubes and centrifuged at 3000 rpm for 10 min. Plasma was removed and stored at -70° for subsequent quantitative enzymatic determination of creatine kinase (CK) in U/L according to the method of Szasz, Gruber, & Berndt (1976) (Boehringer Mannheim Corporation, CK/NAC Cat. No. 816360).

*Leg Endurance Performance.*

Isometric endurance of the thigh muscles was estimated before the hikes, within 5-min after the hikes, and 24 h after the hikes. Subjects began the test by assuming a sitting position with a straight back supported against a solid and flat vertical surface. Arms were crossed over the chest, and knees were bent at a 90° angle. Isometric muscle endurance was recorded as the total time the subject was able to maintain the unsupported sitting position.

Statistical Analysis.

Differences in physical characteristics between groups were determined by paired t-tests. Mann-Whitney rank sum tests were applied to RPE and total muscle soreness data to determine differences between groups. Group comparisons for muscle soreness at the individual sites were determined for each measurement period using Krusal-Wallis rank sum tests. Comparisons of preexercise to postexercise scores for RPE and soreness (total muscle soreness and soreness at each site) were completed by Friedman analysis of variance by ranks. A two-way analysis of variance with repeated measures was used to identify time and group effects for leg endurance performance, run and hike times, CK concentration, and HR response. When a significant effect was identified ($p<0.05$), Student-Newmann Keuls tests were performed to separate the effects of the variables. Values are reported as mean ± standard deviation.

## RESULTS

Physical characteristics of subjects are presented in Table 2. There were no significant differences between groups for these variables. The physical activity survey revealed participants were performing 3-5 aerobic sessions per week, at moderate to high intensity, and for 30-60 min per workout. These sessions included calisthenics and approximately 3 miles of running over moderate, rolling terrain. Two individuals from each group had been performing leg press and squat exercises for the last 2 to 9 months prior to the study. Subjects reported that between 15-25% of their training runs were downhill running.

Table 2. Physical Characteristics of Subjects

| GROUP | Age (yrs) | Height (cm) | Weight (kg) | Body Fat (%) | 3-Mile PFT (min) |
|---|---|---|---|---|---|
| DR (n=12) | 24 ± 5 | 181.0 ± 7.1 | 78.8 ± 9.7 | 11.3 ± 5.3 | 20.2 ± 1.9 |
| C (n=8) | 22 ± 2 | 177.8 ± 10.2 | 78.5 ± 5.2 | 12.5 ± 4.8 | 20.2 ± 1.7* |

* n=7, PFT score unavailable for one subject; DR = downhill running group; C = control group

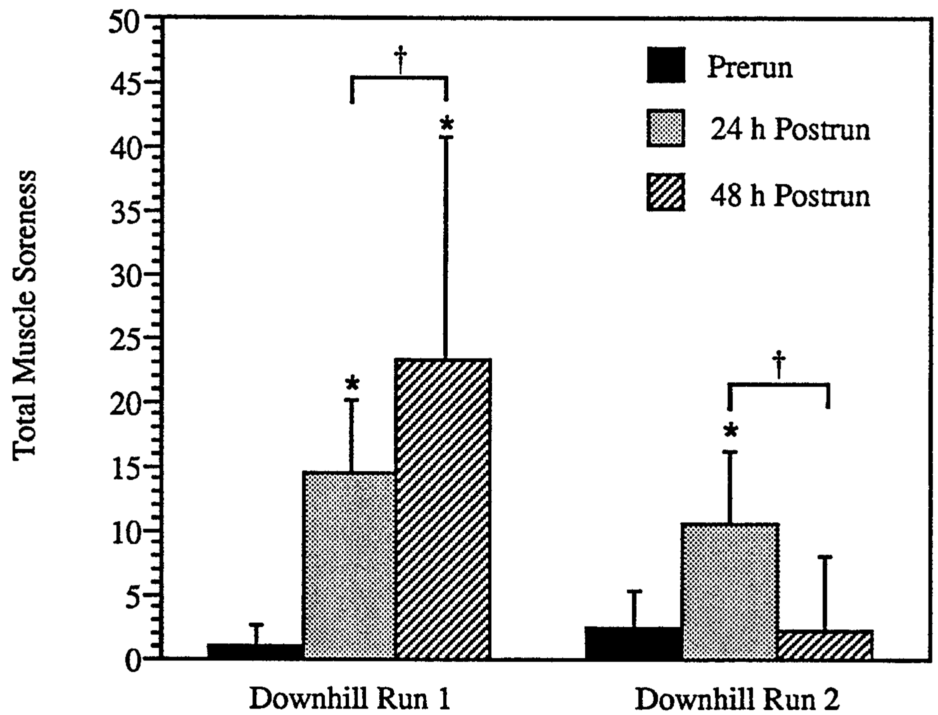
***Downhill Runs***:

Run times for the two downhill runs were not significantly different. Subjects ran at an average (± SD) pace of 6.55 ± 0.40 and 6.76 ± 0.43 min•mile$^{-1}$ for the first and second downhill runs, respectively.

*Muscle Soreness.*

Total muscle soreness scores were significantly less 24 h and 48 h after the second downhill run compared to the first downhill run (Figure 1). Muscle soreness scores at 24 h and 48 h after the first downhill run did not differ significantly, but were significantly greater than the prerun score. For the second downhill run, muscle soreness was significantly elevated above prerun levels at 24 h postexercise, but returned to prerun levels by 48 h postexercise. There was also a significant difference in peak muscle soreness at the different muscle sites. Twenty-four hours after the first downhill run, soreness at the mid-vastus lateralis and lower gastrocnemius sites was significantly greater than soreness at all other sites. Soreness at these two sites were not significantly different from each other. Forty-eight hours after the first downhill run, muscle soreness scores were significantly increased above prerun scores for all sites. There were no significant differences in muscle soreness between the different sites after the second downhill run.

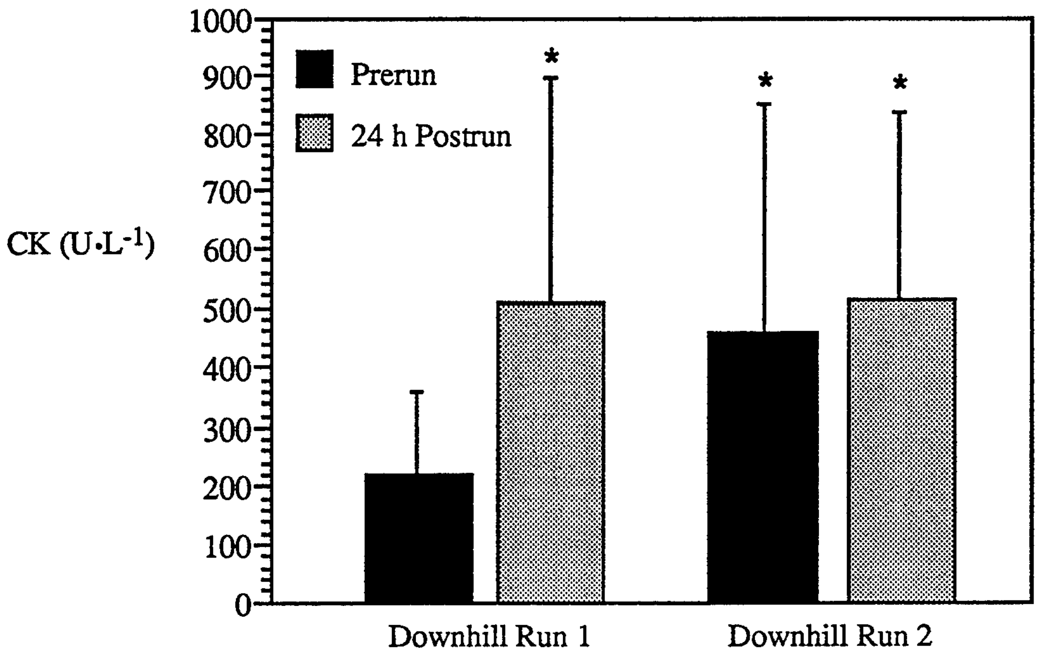
Figure 1. Total leg muscle soreness before and after downhill running. †Muscle soreness after run 2 significantly less than soreness after run 1. *Post scores significantly elevated above pre. Values are mean ± SD.




*Biochemical Indicator of Muscle Injury.*

Twenty-four hours after the first downhill run, plasma CK concentration was significantly elevated above prerun levels, and remained elevated in the remaining sampling periods (Figure 2). After the second downhill run, CK concentrations were not significantly elevated above prerun levels.

Figure 2. Plasma creatine kinase (CK) concentrations before and after downhill running. *Significantly elevated above prerun 1. Values are mean ± SD.




## Hikes:

Dry bulb temperature was significantly lower for the first hike (18.7 ± 1.6°C) compared to the second hike (25.1 ± 1.2°C).

*Hike Times and Heart Rate Response.*

Hike times for the downhill running group were not significantly different from the control group during the uphill or downhill segment for either hike (Table 3). Although HR data was not collected from all subjects (due to failures in the HR recording device), analysis of the remaining data revealed no significant differences in HR between groups during either hike (Table 4). When the HR data from both groups was combined, HR was significantly higher during the uphill segment compared to the downhill segment for both hikes, and HR was significantly higher during the downhill segment of the second hike compared to the downhill segment of the first hike (Table 4). When the hike time data for both groups was combined, subjects hiked significantly slower during the uphill segment of the second hike compared to the first hike (Table 3).

Table 3. Hike Times (min) by Segment for the 6-Mile Hikes

| GROUP | Hike 1 (up) | Hike 1 (down) | Hike 2 (up) | Hike 2 (down) |
|---|---|---|---|---|
| DR (n=12) | 56.1 ± 4.3 | 45.3 ± 3.3 | 58.5 ± 4.9 | 44.7 ± 4.2 |
| C (n=8) | 57.7 ± 2.1 | 45.6 ± 2.3 | 59.3 ± 4.9 | 44.8 ± 3.5 |
| DR & C | 56.7 ± 3.6 | 45.4 ± 2.9 | 58.8 ± 1.1* | 44.8 ± 3.8 |

DR = downhill running group; C = control group; * = significantly slower than hike 1

Table 4. Heart Rate (beats•min-1) by Segment During 6-Mile Hikes

| GROUP | Hike 1 (up) | Hike 1 (down) | Hike 2 (up) | Hike 2 (down) |
|---|---|---|---|---|
| DR | 174 ± 12 (n=10) | 142 ± 16 (n=9) | 170 ± 11 (n=8) | 146 ± 18 (n=8) |
| C | 171 ± 9 (n=6) | 138 ± 10 (n=5) | 175 ± 7 (n=8) | 145 ± 13 (n=8) |
| DR & C | 173 ± 11 | 138 ± 15 | 172 ± 8 | 146 ± 15* |

DR = downhill running group; C = control group; * = significantly higher than hike 1

*Rating of Perceived Exertion.*

Rating of perceived exertion (RPE) was not significantly different between groups. However, when results from all subjects were combined, both the uphill and downhill segments of the second hike were rated as significantly more difficult than the first hike (Table 5).

Table 5. Rating of Perceived Exertion (RPE) by Segment for the 6-Mile Hikes

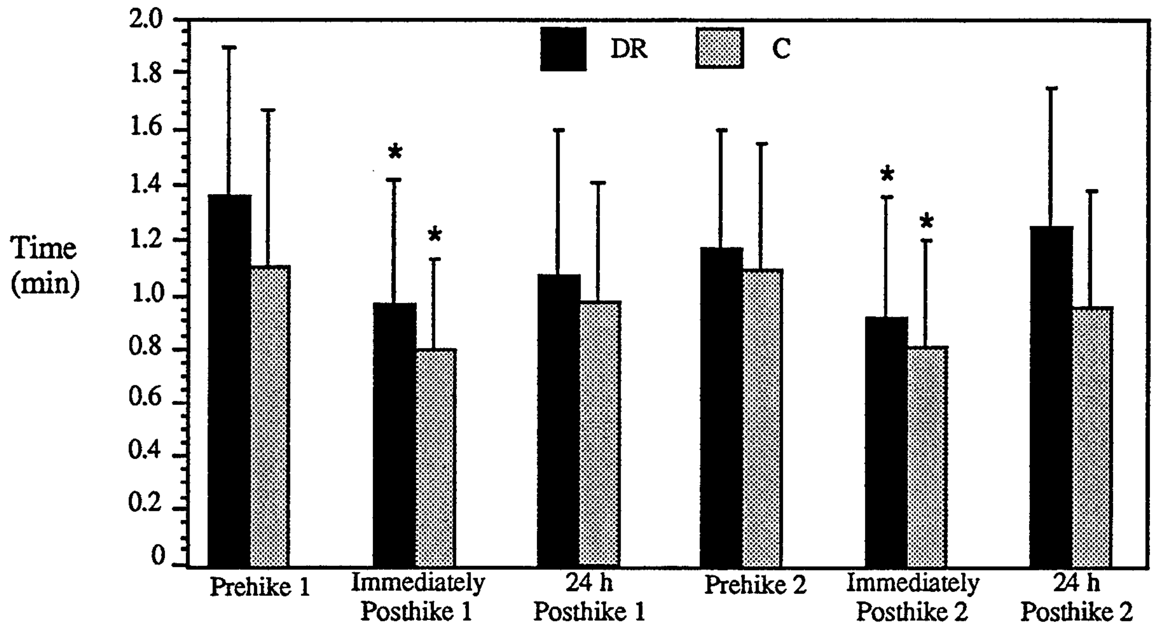
| GROUP | Hike 1 (up) | Hike 1 (down) | Hike 2 (up) | Hike 2 (down) |
|---|---|---|---|---|
| DR (n=12) | 15.7 ± 2.2 | 10.2 ± 2.4 | 15.9 ± 2.5 | 11.3 ± 3.1 |
| C (n=8) | 14.2 ± 2.5 | 9.6 ± 1.9 | 14.9 ± 2.5 | 10.7 ± 2.7 |
| DR & C | 15.1 ± 2.4 | 10.0 ± 2.1 | 15.5 ± 2.5* | 11.1 ± 2.9* |

DR = downhill running group; C = control group; * = significantly more difficult than hike 1
Scale = 6-20

*Leg Endurance Performance.*

Isometric leg endurance time was not significantly different between groups after hike 1 or hike 2 (Figure 3). However, when the groups were combined, leg endurance immediately after both hikes was significantly reduced from prehike endurance. Isometric leg endurance 24 h after the hikes was not significantly different from prehike or immediately posthike endurance.

Figure 3. Isometric leg endurance before and after 6-mile mountain hikes. No significant differences between groups. *Leg endurance immediately posthike significantly less than prehike. Values are mean ± SD. DR = downhill running group; C= control group.




*Biochemical Indicator of Muscle Injury.*

Plasma CK concentrations are presented in Table 6. Two subjects (one from each group) reported post hoc, that they performed novel arm weight lifting exercises between the second downhill run and the first hike. These subjects were excluded from the analysis since novel arm exercise can result in significantly increased CK concentrations (Clarkson & Tremblay, 1988; Evans & Cannon, 1991). No significant differences in CK was detected between groups for any sample period. When the downhill running group and the control group were combined, CK concentration was significantly elevated above prehike values, 24 h after the first hike.

*Muscle Soreness.*

Total muscle soreness scores were significantly increased above prehike scores 24 h after hike 1 for both groups (Figure 4). Muscle soreness was not significantly different between groups for any time period. When scores from both groups were combined, there was a significant increase in muscle soreness from the prehike rating compared to all time periods (except 48 h after the second hike). Muscle soreness at 24 h and 48 h after hike 1 did not differ significantly from

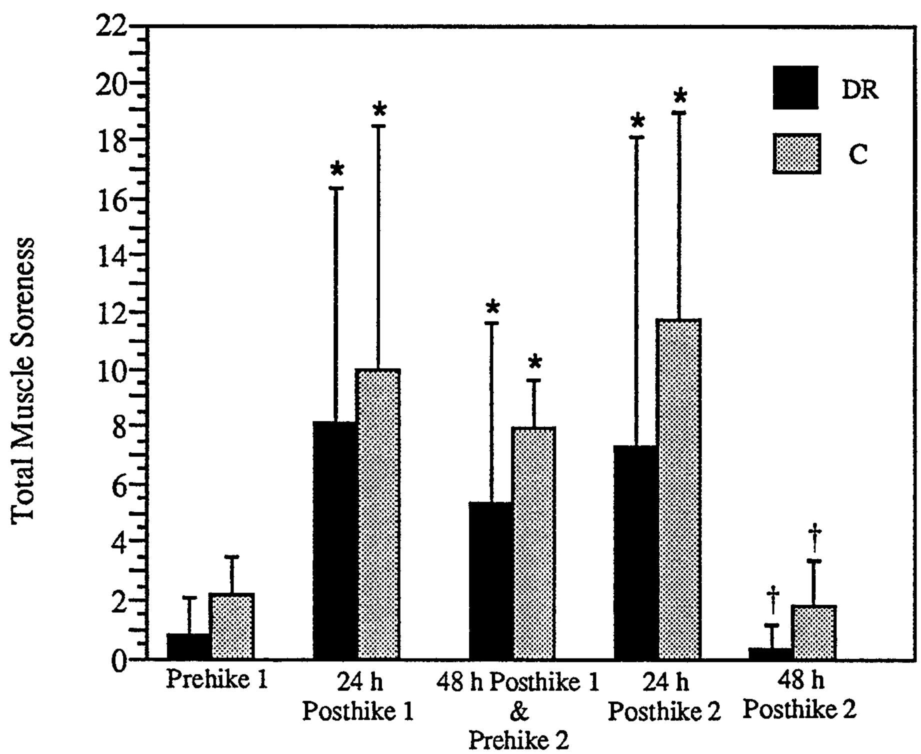
each other. At 48 h after the second hike, muscle soreness scores returned to prehike levels (Figure 4). The muscle soreness scores did not differ among muscle sites at any time.

Table 6. Plasma Creatine Kinase Concentrations (U/L) Before and 24 h after Hikes

| GROUP | Prehike 1 | 24 h Posthike 1 | Prehike 2 | 24 h Posthike 2 |
|---|---|---|---|---|
| DR (n=11) | 156.4 ± 64.8 | 534.8 ± 619.1 | 384.6 ± 423.9 | 439.8 ± 418.2 |
| C (n=7) | 241.6 ± 156.0 | 468.4 ± 192.1 | 324.3 ± 158.1 | 537.4 ± 345.5 |
| DR & C | 189.5 ± 113.5 | 509.0 ± 489.5* | 361.2 ± 339.8 | 477.8 ± 383.9 |

DR = downhill running group; C = control group; * = significantly greater than prehike 1

Figure 4. Total leg soreness before and after 6-mile mountain hikes. No significant differences between groups. *Significantly elevated above prehike 1; †Significantly lower than all other time periods except prehike 1. Values are mean ± SD. DR = downhill running group; C= control group.



## DISCUSSION

The results from the field downhill training runs are consistent with previous laboratory investigations. Increases in muscle soreness and plasma creatine kinase (CK) concentration have consistently been reported, following an unaccustomed bout of downhill running (Byrnes et al., 1985; Donnelly, McCormick, Maughan, Whiting, & Clarkson, 1988; Law et al., 1994; Pierrynowski, Tudus, & Plyley, 1987; Schwane et al., 1987), eccentric cycling (Evans et al. 1986; Friden, Sfakianos, & Hargens, 1989), and bench stepping (Newham, Jones, & Edwards, 1983). Our findings confirm the findings of others that a single downhill run is sufficient to provide some protection against muscle soreness when a second downhill run is performed 1 to 6 weeks later (Byrnes et al., 1985; Law et al., 1994; Pierrynowski et al., 1987).

The significant increase in plasma CK concentration after the first downhill run, and its persistent elevation after the second downhill run, has also been previously documented (Law et al., 1994; Golden & Dudley, 1992). This is in contrast to others who reported a decrease in CK concentration following a second downhill running bout (Donnelly et al., 1988; Pierrynowski et al., 1987; Schwane, Johnson, Vansenakker, & Armstrong, 1983). However, these studies used training protocols that involved longer periods between bouts compared to our study (i.e., 3 to 10 weeks vs. 1 week). While peak elevations in CK typically occur 24 h to 48 h after an initial eccentric leg exercise bout (Ebbeling & Clarkson, 1989; Tidus & Ianuzzo, 1983), peak elevations have been reported at 4 to 6 days after exercise, with CK remaining elevated up to 7 to 9 days postexercise (Evans, 1987; Newham et al., 1983). The sustained elevation of CK after the second downhill run in the present study may be explained by the performance of this downhill run before CK returned to prerun levels (Golden & Dudley, 1992). Interpretation of the CK response after the downhill runs and hikes is confounded by the reported high inter-subject variability of this marker. Clarkson & Ebbeling (1988) observed that sedentary subjects either had no increase in CK (non responders, <200 U/L), a moderate increase in CK (low responders, 300-600 U/L), or a high increase in CK (high responders, >1000 U/L) after performing a novel eccentric exercise bout. Similarly, a wide range of CK response (91 to 1503 U/L) was seen in our subjects after a novel eccentric bout of either downhill running or hiking.

The hypothesis that two downhill running bouts would significantly reduce symptoms associated with unaccustomed mountain hiking was not supported by this study. Subjects in the downhill running group did not exhibit greater reductions in muscle soreness, plasma CK, or in isometric strength loss following either hike, compared to the control group. Furthermore, hiking performance, measured by total hiking time, was not reduced by prior downhill running.

A factor that may have contributed to the outcome of this study was the mode of exercise (i.e., running) selected to prepare the muscles for hiking. Although downhill running and the downhill phase of hiking are similar activities, there are differences in stride frequency, forces absorbed by the muscles, and body mechanics. For example, the magnitude of force produced by the body during landing is affected by the speed and angle of the downhill work, and the weight

carried during the activity. As speed increases and grade decreases, peak impact force and force absorbed by the muscles increase and are sustained for a longer period of time (Buczek & Cavanagh, 1990; Dick & Cavanagh, 1992). Compared to downhill walking, the increased speed and stride frequency with downhill running increases peak impact force and the rate of loading by the muscles and connective tissues (Buczek & Cavanagh, 1990). Buczek & Cavanagh (1990) also concluded that the higher forces absorbed by the muscles contribute to the soreness observed with downhill running. This finding may explain the higher soreness scores recorded after the downhill runs (range 10 to 23), compared to after the hikes (range 6 to 12).

Factors such as gravity and total weight transported can influence which muscles are stressed, and to what degree, during downhill exercise. Gravity contributes to the decreased energy cost of eccentric exercises by moving the load downward and activating fewer muscle fibers (Pimental, Shapiro, & Pandolf, 1982). However, gravity can also increase energy demand in some muscle groups as they resist gravity at fixed velocity (Pimental et al., 1982). In our study, the mountain hikes, unlike the downhill runs, were completed by subjects carrying a pack load equal to 30% of their body weight. This increase in total weight transported, compared to downhill running, could translate into increased fatigue in selected muscles and result in a shift in posture (Pimental & Pandolf, 1979). Carrying additional pack weight can force an individual to lean forward to bring the center of gravity back over the base of support. This posture results in increased activation of leg and back muscles required to resist the downward pull of gravity and maintain balance (Gordon, Goslin, Graham, & Hoare, 1983; Pimental & Pandolf, 1979). Gordon (1983) suggests that the excess forward leaning (flexion) observed during load carriage is resisted by hamstring and semispinalis muscle groups. Resistance by these muscle groups can result in muscle strain and later muscle soreness. Additionally, as load is increased, the activity of motor units in the tibialis anterior, vastus lateralis, erector spinae and trapezius muscles are also increased (Gordon, et al., 1983; Norman & Winter, 1980). Increased activation of the hamstring and tibialis anterior muscle groups during load carriage in our study is suggested by the muscle soreness ratings of our subjects. While not significantly different, muscle soreness was greatest in the vastus lateralis, tibialis anterior, and the hamstring regions 24 h after the first hike. In contrast, muscle soreness was greatest in the vastus lateralis, gastrocnemius, and gluteal regions for the downhill runs. These points suggest that the magnitude and frequency of stress imposed on muscles and the activation of specific muscles were different for the downhill runs compared to the hikes.

The concentration of plasma CK after the hikes further supports the view that the downhill running program did not adequately condition the muscle groups involved in the mountain hikes. In contrast to other studies, CK was not significantly attenuated when a second eccentric exercise (i.e., the first hike) was performed 2 weeks after novel eccentric exercise (i.e., downhill running) (Byrnes, et al., 1985; Newham, et al., 1987; Law et al., 1994).

It is also possible that comparisons in this study were confounded by differences in environmental and physical conditions between the two hikes. For example, we observed from

posthike interviews, that several participants felt their ability to perform maximally during the second hike was affected by the presence of blisters as a result of the previous hike. The significantly warmer environment of the second hike may have also reduced the participants' ability to perform. The effect of temperature on exercise performance has been demonstrated by a significant increase in heart rate (15-20 beats•min$^{-1}$) when temperature was increased 10 to 20°C while subjects exercised at 60 to 70% of maximal aerobic capacity (Nadel, Cafarelli, Roberts, & Wenger, 1979). Exercising in a hot environment compared to a cooler environment has also been shown to increase energy expenditure at submaximal work loads and to reduce maximal oxygen uptake (Dimri, Malhotra, Gupta, Kumar, & Aora, 1976). Knapik et al. (1990) reported longer march times for a second 12-mile road march when temperatures increased by 16°C, during which soldiers carried a 46 kg load. The effects of temperature on our subjects was reflected by a higher heart rate response (146 beats•min$^{-1}$ vs. 138 beats•min$^{-1}$), a slower hiking time (58.8 min vs. 56.7 min), and higher ratings of perceived exertion (15.5 vs. 15.1 and 11.1 vs. 10.0) in the second hike compared to the first hike. Hike times may have also been influenced by the subjects' motivation to perform maximally during both hikes. Although the start times were staggered and participants were instructed to put forth their best effort, some subjects changed their pace to hike alongside other participants.

A secondary purpose of this study was to provide documentation on how leg muscles respond to a novel mountainous hiking exercise (with pack weight). The following discussion is based on combined data from participants in both the downhill and control groups. In general, the observations made during and after hiking are similar to observations previously reported for unloaded downhill running and walking (Byrnes, et al., 1985; Balnave & Thompson, 1993; Law, et al., 1994; Newham et al., 1983).

Findings of an immediate decrease in leg performance (isometric endurance) following unaccustomed eccentric exercise have been reported in other studies of leg eccentric exercise. (Balnave & Thompson, 1993; Newham et al., 1983; Newham et al., 1987). Stepping exercise resulted in a decrease in maximal voluntary contraction of the knee extensors immediately after exercise, but not 24 h later (Newham et al., 1983). This finding agrees with the present study's observation that short-term loss in leg endurance was recovered 24 h after the hikes.

Muscle soreness responses after hiking also followed a similar pattern as downhill running and downhill walking studies (Balnave & Thompson, 1993; Law et al., 1994; Schwane, et al. 1983; Schwane et al., 1987). In the present study, a single hike was sufficient to reduce muscle soreness in a second hike performed 2 days later. Muscle soreness, which peaks and then disappears earlier than CK concentration, does not appear to be affected by the performance of a second bout only 2 days later (Evans et al., 1986; Evans & Cannon, 1991; Newham et al, 1987).

Unlike muscle soreness, the short period of time between the hikes was not sufficient for CK concentrations to return to prehike values. The plasma CK responded in a similar manner as

after downhill runs. Large variations in CK may have been influenced by the presence of "responders" and "non-responders" (Clarkson & Ebbeling, 1988).

In summary, the two downhill runs did not prevent muscle soreness, muscle damage (as measured by plasma CK), or short term isometric strength losses associated with subsequent mountain hiking. We can not be certain of the efficacy of the downhill training program since several uncontrolled factors may have influenced the outcome measures. The results of this study may have been different if we could have controlled the thermal environment, prevented or reduced the incidence of blisters, increased compliance to the hiking instructions, and used a less variable marker of muscle injury. Clearly, the mode of exercise and the addition of external load influence the degree of eccentric muscle damage and adaptation. In order to produce the maximal protective effects associated with eccentric training, additional research is needed to determine the importance of training specificity.

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P. G. Law, H. W. Goforth, Jr., S. E. Kaupp, W. K. Prusaczyk, K. W. Schneider, J. L. Reid

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
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Unaccustomed eccentric exercise (e.g., the landing phase of running, hiking downhill, walking down stairs) can result in severe muscle soreness (MS), strength loss, and muscle damage. However, personnel may be able to prepare the muscles in advance by performing a similar but less time-consuming eccentric activity. This study determined if downhill running could reduce adverse symptoms that may be associated with a subsequent novel mountain hiking exercise. Special operation volunteers were assigned to either a treatment (downhill running) group (n=12; DHR) or a control group (n=8; CRL). DHR performed two 3-mile downhill runs (1 week apart), while CRL followed their normal training schedule. Two weeks after the second downhill run, both groups completed two 6-mile mountain hikes (2 days apart) while carrying 30% of their body weight. MS, isometric leg endurance, and plasma creatine kinase (CK) were measured before and after the downhill runs and the hikes. Subjects in DHR exhibited neither significantly greater reductions in MS, CK, or in strength loss after either hike, nor a significant improvement in hiking performance compared to CRL. Therefore, downhill running does not appear to provide significant protection against MS, muscle damage (CK), or short-term strength losses that accompany unaccustomed mountain hiking (with pack weight).

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